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ASSESSMENT OF THE FEASIBILITY OF AN EXTENDED RANGE HELICOPTER OPERATIONAL STANDARD FOR OFFSHORE FLIGHTS

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Abstract

The accident rate of rotorcraft has improved significantly over the years but at a slow pace, and in any case the number of accidents per flight hours is one or two orders of magnitude higher than that of commercial aircraft, a consideration that could be reasonably related to the inherent higher risk associate with rotorcraft operations. This represent a strong evidence of the necessity to introduce airworthiness operation standards also in the rotorcraft community, as an effective mean to improve safety records, borrowing from the experience done in the commercial air transport community with the introduction of ETOPS. In this paper, a first proposal of development of a safety standard for helicopter offshore operation is discussed together with the possible support to this development that could be given by the EU H2020 project NITROS.

1. INTRODUCTION

Helicopter accident and fatal helicopter accident rates have fallen for three consecutive years since 2014. This is clearly shown in the report of the International Helicopter Safety Team (IHST) presented at the HAI Heli-Expo this year[1]. However, the current rate is still too high to be considered acceptable. Commercial airplane flights have a rate of 26 fatal and non-fatal accidents per 10 Million movements[2], which means about 13 accidents per 10 million flights.* Already in 2000 Harris et al.[3] estimated that it was ten times more likely to be involved in an accident if flying in a helicopter than in turbojet fixed-wing aircraft, while Fox in 2004[4] gave as figure for the accident rate for Bell helicopters of 3.9 per 100,000 hours, that is two order of magnitude higher than that of commercial airplane.† In any case, the comparison of the safety records between commercial aeroplane and rotorcraft operation shown in the Annual Safety Review 2017 edited by EASA is clear[2] both in terms of global accident rates and in terms of fatal vs. non-fatal accidents.

Of course airliners operate from airport to airport, while rotorcraft are employed in many complex operations: offshore operations, search and rescue, coastguard, firefighting, disaster relief, territorial control, monitoring and inspection, heavy-lift support to construction and other sectors, aerial filming and media support, etc., and this makes a huge difference in the realistic safety targets that can be achieved, given the significant time spent close to terrain and obstacles, often in harsh envi-

*Assuming that the average flight time is close to 2 hours.

†Unfortunately, it is very difficult to retrieve data on accidents per flight hours that is the typical safety rate used in aviation, because it is still problematic to collect flight hours for the global helicopter fleet.

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ronment. However, the inherent higher complexity and risk of operations should rather be considered as an incentive to develop operation standards, despite the large variety of type of operations may make this objective more difficult to achieve.

To better frame the current rapidly evolving situation, as predicted by the 20-year Annual Forecast by the american Federal Aviation Administration (FAA), rotorcraft hours flown are expected to grow at a rate of 2.2% per year[‡], given the strategic roles covered in many critical community services by rotorcraft. And this rate of growth does not consider the possible explosion of *on-demand* and personal aviation services for urban mobility based on Vertical Take-Off and Landing (VTOL) air vehicles that are currently attracting large investments worldwide[5].

An interesting proposal on how to properly manage risk, and thus increase safety, has been launched by Leonardo Helicopters[6,7]. The idea is to develop *design and operation* rules for helicopters in a fashion proportional to the specific risk faced. Safety improvements should not be linked just to airworthiness of the design, they should rather be linked to operational risk. The risk in fact is the combination of the predicted severity — i.e. criticality — and likelihood — i.e. probability — of the potential effect of a hazard[8], and so it is a concept inherently associated with a specific operation. In fact, risk is tightly related to operation and should be considered a function of many parameters related to the environment where the operation takes place, i.e. populated, congested, hostile as of mountain areas. This means that the higher is the risk of the specific operation to be performed, the more stringent should be the design requirements.

Leonardo Helicopter launched the effort to set up an Extended range Helicopter Operation Standard (EHOPS)[6]. The Leonardo proposal is based on a commercial airplane operation standard success story, ETOPS (Extended-range Twin-engine Operational Performance Standards), introduced in 1985 to apply an overall level of operational safety for twin-engine aeroplanes which was consistent with that of the three and four-engined aeroplanes, the only types allowed to fly transoceanic routes at that time, to which no restrictions were applied. Today's rule establishes regulations governing the design, operation and maintenance of certain airplanes operated on flights that fly long distances from an adequate airport[9].

A similar regulation associated with a specific operation in order to quantify the risk and bring it to an acceptable level could be developed for rotor-

[‡]https://www.faa.gov/data_research/aviation/aerospace_forecasts/ retrieved March 15, 2018

Figure 1: Offshore operation for rotorcraft.

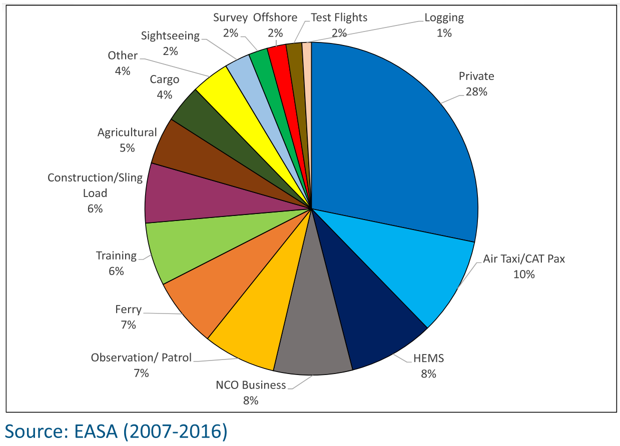

Figure 2: Percentage of fatal accident by type of operation. Source EASA published in IHST 2018 Worldwide Partner Panel.[1]

craft as well. In this case, the proposal of Leonardo Helicopter[7] is to tackle one of the most hostile environments for rotorcraft operation, that is the offshore case (see Figure 1), although the analysis reported by EASA in the IHST 2018 report[1] shows that offshore is definitely not the largest contributor to the number of fatal accident in rotorcraft, see Figure 2.

NITROS — Network for Innovative Training on ROtorcraft Safety[§] — is a project launched in 2016 under the umbrella of the Marie Skłodowska Curie Joint Doctorates Programme in the European Union aim to train (up to doctoral level) a new generation of talented young engineers to become future specialists in developing innovative approaches to address rotorcraft safety issues[10]. To increase the awareness of safety issues of the researchers that are participating in the NITROS project it has been decided to perform this assessment of the feasibility of the EHOPS for offshore operations as a team work.

[§]https://www.nitros-ejd.org/

The paper presents the foundations of the investigation to be performed by the twelve researchers on the feasibility of the EHOPS Standard and on the elements that should be included in this standard.

2. CURRENT STATUS OF ROTORCRAFT FLIGHT SAFETY

The safety of rotorcraft is clearly related to unique missions they are asked to perform. Rotorcraft are employed in many complex operations close to terrain and obstacles and in harsh environments, and this makes a huge difference in the realistic safety targets that can be achieved. Additionally, rotorcraft have naturally (i.e. without any artificial stability augmentation) limited stability; they have significant cross-couplings of controls, being, for some types, potentially difficult for the pilot to operate without losing control in harsh environmental conditions; when the visual conditions degrade and the pilot has difficulty seeing the terrain and horizon references, there is a high risk of spatial disorientation, with consequent departure from the desired flight trajectory. So, it seems very important to consider safety not as simply related to airworthiness of the design but linked also to operational risk.

Part failure represents a very small fraction of accidents, so airworthiness problems contributes little to the causes that must be primarily sought in the interaction of the vehicle with the other elements of the aircraft[4,2]. In an analysis of accident statistics between 1995-2010[11], only 5% of accidents belong to airworthiness failures, while 40% are related to pilot awareness, skills and judgment, 10% are related also to the risk associated with environmental conditions and another 5% to mission risk associated with hostile areas of operations.

In the 1950s and 1960s the US Air Force Ballistic Missile Division introduced the concept of *system safety*, where one of the key aspects was that everything contributes to the response of the *system* and so all failures — of parts of the aircraft but also of the human operators, the management system, and the environment — affect the final outcome of the system[4]. In the helicopter world most of the times the system has been considered the entire aircraft[4]. However, to manage risk properly, and so increase safety, it is important to take into account the other elements that contribute to the system and consequently develop an approach to safety that is linked to operational risk. The designer must be able to identify clearly the risks associated with any design choice in relation to the different operative scenarios. Additionally, it will allow to erase the myths such as "Twin-engine helicopters are always safer than single engine helicopters. The rest of the aircraft other than the engines are the same on single or twin-engine helicopters, so it can be disregarded"[4], that tend to ignore that risk is intimately associated with the type of mission, and that in specific situations with the appropriate safety assessment a flight on a single engine rotorcraft could be safer.Disproving such a myth in aviation was perfectly exemplified by the development of the ETOPS.

3. ETOPS, A SUCCESS STORY

The ETOPS is a set of regulations for passenger aircraft developed as an exception to overcome the effect of the FAA 121.161, denominated the 60-minute rule. In fact in 1953, the FAA adopted a rule that prohibited aircraft with less than four engines from flying more than 60 minutes to reach the nearest suitable airport in response to an engine failure.

The 60 minutes rule was the logical consequence of the comparatively low reliability of piston engines, and of an unconditional faith on the general rule that more engines are always better, no matter how the rest of the systems of the aircraft are conceived.

The higher reliability of jet engines, that required also less maintenance, sparked the idea on aircraft manufactures to develop airliners with less engines that could be more fuel-efficient and have lower operational costs and better operational flexibility. This idea was supported by airlines who saw the economic advantage.

The initial opposition of the regulator was not specifically related to engine reliability, but more to the capabilities of a single engine to power critical sub-systems while being the only source of thrust[12]. A clear example was related to de-icing systems: operating an aircraft on single engine will force to fly at peak icing altitude, so it was correct to ask if the only active engine was enough to power electric, hydraulic avionic and de-icing systems.

In July 1984 the FAA issues a draft advisory circular for twin-engine extended operations including six main design criteria:

1. show an acceptable low risk of double engine failure from independent causes;
2. demonstrate the reliability of the propulsion system by in-service experience;
3. ensure that critical systems could be operational if engine fails;
4. assess the air carrier and manufacturer's maintenance programs to demonstrate that they are able to reach the reliability level required;

5. review the training, operation and maintenance programs of airlines;

6. apply fail-safe criteria for the design of critical systems.

Interestingly, the introduction of ETOPS did not rely simply on a request of higher reliability of engines, but sparked the attention to the redundancy of systems, general reliability and also to training and maintenance procedures. In the end, it resulted in a standard designed to preclude failure and malfunction that could cause a diversion from the intended mission, or, in case a diversion is necessary, to perform it in the safest way[12]. This called for several changes:

- the aircraft and engine manufacturers were forced to follow design processes that resulted in higher reliability;

- the airlines were required to qualify independently for extended range operations, providing detailed information about the maintenance, inspection and replacement programs.

Several important safety features were enhanced with the constraint to keep the level of safety for the length of the longest possible diversion, like onboard fire suppression systems.

The benefit of this risk assessment-based approach, lead to application of the ETOPS approach to all aircraft. Airlines started to apply ETOPS practice to ETOPS-exempt aircraft, and the same happened for design procedures. In 2007 the definition of the acronym was changed to simply "extended operations" to clarify that the set of rules developed should be applied to all passenger airplanes with more than one engine.

So, it is possible to state that the introduction of ETOPS "improved the safety of commercial aviation: no ETOPS flight has been lost because of a danger that ETOPS was meant to address"[12]. Additionally, all actors gained advantages. The manufacturers were allowed to better market aircraft; in fact, twin-engine products have significantly increased the number of flying aircraft. Airlines have more flexible aircraft, that better satisfy the request of passengers of more direct flights. The regulation authorities promoted safety in civil aviation, and the society as a whole benefited from the faster diffusion of smaller, more fuel-efficient airplanes. Currently, more twin-engine aircraft cross the transoceanic routes that three- or four-engine ones.

4. EHOPS CERTIFICATION FOR HELICOPTER OPERATION

The application of ETOPS principles to Helicopters, in what has been termed Extended Helicopter Operations (EHOPS) has been recently proposed in Ref. 7.

The application of this idea to offshore tasks is particularly challenging. Offshore operations performed by helicopters are typically related to: movement of people to and from their workplaces on offshore facilities and vessels; equipment inspection; freight transportation; emergency evacuation; search and rescue missions; construction and maintenance of offshore wind farms; construction and maintenance of offshore oil and gas platforms; various ship operations. All those operations pose specific risks to helicopter operations related to the adverse environment where they are performed.

The starting point to understand the possibility to apply the ETOPS approach to rotorcraft offshore operations is the analysis of the AMC-20-6[9]. It is possible to map the different elements discussed in this standard to the following seven topics:

1. System requirements and design

2. Safety Requirements for EHOPS

3. Maintenance Requirements for EHOPS

4. RFM Procedures for EHOPS

5. MMEL/MEL for EHOPS operation

6. Human factors and operational aspects

7. Training aspects

An initial analysis of all those aspects could be found in Ref. 7.

It is important to note the large emphasis that the ETOPS design criteria pose on fail-safe criteria for design. In helicopters there are several systems where single Hazardous and Catastrophic failure modes are possible, as either single failure modes or single failure modes in association with failure of monitoring system. Those are particularly critical for the parts that belong to the Rotor System, including the Control Chain and the Rotor Drive System.

In this case the approach to be followed could not be based on reliability by redundancy or fail-safe approaches, as often used in ETOPS, but more on high reliability obtained as combination of design, maintenance, inspection and replacement requirements. Damage Tolerance including safety margins vs. external, maintenance induced damages and manufacturing flaws, must be combined with appropriate and reliable health monitoring systems to reach an acceptable risk of failure to be demonstrated, also by in-service experience as done for ETOPS.

Additionally, further detailed analysis in the case of helicopters with respect to airplanes will be required for take-off and landing procedures. Starting from the definition of operations categorization based on Take-Off and Landing operations, Performance Class 1 & 2 (PC1 & PC2) are scrutinized in the context of offshore operations. Both performance classes require that in case of a critical power-unit failure, performance must be available to enable the helicopter to safely continue to an appropriate landing area, unless the failure occurs during take-off or landing. In PC1, a failure before reaching the take-off decision point (TDP) or after passing the landing decision point (LDP) must leave the helicopter with the capability to land within the rejected take-off or landing area. In PC2, however, it is sufficient that the helicopter is able to make a forced landing. PC2 does not seem adequate, since it exposes the helicopter to potentially catastrophic risks due to engine failure, which are not paralleled by analogous classifications for Commercial Air Transport (CAT) related to fixed wing aircraft. PC2 operations are currently permitted by operation regulations with additional measures that are intended to mitigate the risk exposure associated with some engine failures.

In any case, in the definition of extended operation standards, helicopters present an additional degree of freedom that should be accounted: the capability to land in areas not specifically designed as landing areas. In offshore operations, continuing to an appropriate landing area might represent too strict a requirement. Helicopters for offshore operations have the capability to ditch. The application of ETOPS principles requires one to consider failure modes that might force the helicopter to land on water.

Of course, ditching is less desirable than landing on an appropriate area. As such, two types of analysis need to be taken into account. In the first scenario, an appropriate landing area must be reached. In the second one, successfully ditching in safe conditions is considered. The primary objective would be to use ETOPS principles to avoid ditching in the first place. Both analyses aim at defining what changes are required in the design of the helicopter to reach an acceptable diversion distance and time to reach what in the context of EHOPS is equivalent to the alternate landing site of ETOPS, i.e. a safe landing site as the preferred choice or, as a second choice, a safe place for successful ditching and subsequent rescue.

Typically, helicopters operate within much shorter distances, compared to large jet airliners. However, they also fly at much lower cruise speeds, which may further reduce in case of one engine inoperative (OEI) conditions. Furthermore, especially in case of offshore operations, there might be no alternate landing sites, or they might be at distances at least comparable to those of the departure or destination sites. As such, very often an alternate landing site is either not available or not preferable, in terms of distance and time, unless the closest between the departure or destination sites becomes unavailable for other reasons (e.g. weather conditions). Typically, in those cases, diversion times between 30 min and 2 hours would be necessary to avoid ditching. However, such a duration is beyond the current and foreseeable safety objective of critical systems, like rotors and transmission, in terms of residual risk of continuous operation in case of many types of first failures. Consequently, many operations might not meet the requirement of reaching a safe landing site. In those cases, the distance and time required to reach a place for safe ditching and subsequent rescue is the only possibility to define a possible EHOPS route. Considering the limited range and speed of helicopters, compared to those of large jet airliners, typical flights can be considered local in terms of variability of geographical and environmental characteristics, making the definition of risk scenarios of EHOPS operations easier for specific geographic areas and seasons. These aspects can play a very important role in defining the sustainability of commercial operations, which involves the capability of successfully operating routinely with sufficiently high success rates, in terms of accomplishing the mission instead of aborting it, regardless of, e.g., environmental conditions.

Scenarios can significantly change, within a specific geographical area, for example because of the season. Different seasons imply different expected average weather conditions, for example in terms of likelihood of encountering icing conditions, or of passenger and crew survival time in water after a successful ditching that results in an evacuation of the helicopter prior to rescue. Encounters with icing conditions could result in cancellation of the flight, in case the helicopter is not equipped with appropriate anti-icing systems (both in terms of capabilities and reliability), whereas the need to ensure safe rescue in case of ditching would require the route to remain within a prescribed maximum distance from available search and rescue (SAR) services in the related Risk Scenario. Allowing the possibility of safe ditching alleviates the requirement of long diversion times, but introduces the need to update the helicopter in order to provide adequate ditching capabilities, along with the related requirements on operations, maintenance and training. The analysis of the risk scenario could introduce further limitations, e.g. on the visual conditions (for example restricting operations to daylight conditions). Other elements in the risk scenario that may be characteristic of the type of operations are, for example, bird impact, which unlike large fixed wing jet airliners is not limited to take-off and landing, but may be present during much longer operation phases, and lightning strikes. Several types of reliability issues need to be addressed:

- engine reliability in relation to loss of thrust control (LOTC) and in flight shut down (IFSD) rates, with special attention to the risk of dual engine failure in one flight;
- system level reliability, including reliability of secondary / back-up systems or warning systems which, in case of false indications, could induce the crew to carry out an unnecessary ditching;
- capability of design features targeted to allow continued operation in the event of a failure (e.g. fire suppression, main gear box (MGB) loss of oil capability, time-limited electrical system capability).

Periodic reviews, at least yearly, of the risk scenarios is necessary, since some of the sources of risk may vary. EASA's Annual Safety Review, for example, is a tool that may be used to produce Safety Risk Portfolios based on events happened during the preceding years.

The definition of agreed risk scenarios for EHOPS operations is a key element for innovating the approach to enhancing helicopter operations, which must be matched with a Safety Objective. Meeting such objective requires combining compliance to design requirements by the OEM with compliance to operational requirements by the operator. From an operator's point of view, the Mission Related Safety Objective of a single mission may need to be complemented with a Cumulative Safety Objective, which takes into account the number of flights performed to carry out the intended business in a given period of time. Finally, a key aspect is the validation of the initial assumptions that are inevitably made both for design and operations. As for ETOPS, also EHOPS requires a feedback of service data, to confirm or refine the initial assumptions based on experience. It is clear that EHOPS management procedures are as important as EHOPS requirements.

5. NITROS CONTRIBUTION TO EHOPS SET-UP

In NITROS, a unique cross-disciplinary research and training program was set up encompassing Control Engineering, Computational Fluid Dynamics (CFD), Modelling and Simulation, Structural Dynamics, and Human perception cognition and action. The project is aligned with the European Union endeavor to reduce the rate of aviation accidents by tackling all critical aspects of rotorcraft technology. Twelve young researches are taking part in a dynamic network composed by engineering schools (Politecnico di Milano, Liverpool University, Glasgow University and Delft University), and industrial partners that include Leonardo Helicopters, a rotorcraft manufacturer, Bristow, a major operator, CAA Civil Aviation Authority in UK, a certification body, EUROCONTROL, a regulatory body, and two independent research centers: NLR The Netherlands Aerospace Centre, specializing in aviation research, and the Max Plank Institute for Biological Cybernetics, which specializes in all aspects related to human-machine interface.

Exploiting the analysis undertaken by the European branch of the IHST[11], three main threats to rotorcraft safety have been identified, which led to the following three research objectives in NITROS:

- develop a detailed framework for rotorcraft modeling, integrating rigid-body and aeroservoelastic modeling features, capable of dealing with structural, propulsion, or mechanical system failures;
- understand how humans can safely and efficiently use and be interfaced with rotorcraft technology;
- enhance the understanding of the unique and complex aerodynamic environment in which rotorcraft are working, often in hostile conditions of wake encounter threats, undesirable interactions with obstacles, icing, and brownout conditions.

The methodological approach developed within the NITROS training program will be focused on the identification of the interconnections that exist among the three pillars that are often overlooked during the design.

Each research program focuses on a problem that affects the safety of current or future rotorcraft configurations. The possible implications of the problem in terms of manufacturing, operations and certification procedures will be thoroughly discussed with the industrial partners.

The NITROS researchers will develop two teams to work on EHOPS.

The first team will focus on the aspects of EHOPS related to the interaction with the environment. In particular the aspects of systems reliability to ensure EHOPS operation especially in case failure, flight in degraded environment, specific hazards, and take-off and landing procedure will be reviewed.

The second group will be more focused on the interaction with humans, looking into aspects like levels of automation and minimum levels to be required in case of failure, and training levels and capabilities required to perform offshore operations in failure conditions.

6. CONCLUSIONS

The introduction of an extended operations standard (EHOPS) for offshore helicopter operation is considered feasible even though specific peculiarities of rotorcraft design will set some challenges to overcome.

The oil and gas and offshore operator industry over the years set in place several safety improvements and initiatives, related to offshore heli-deck standard and landing procedures, health monitoring system employment, collision avoidance systems, flight in poor weather conditions, flotation systems. However, it is the time to transform all those initiative into something more systematic to pool the different experiences into a standard.

This initiative, as it has been for the ETOPS, could result in one of the rare compromises that can leave everyone happy, a win-win situation where all actors (manufacturers, operators, regulators, passengers, aviation professionals, society at large) could gain advantages.

In this sense, also NITROS researchers, by giving their contribution to EHOPS exploiting their individual expertise, may receive in return a significant professional growth by deepening their knowledge of operational safety.

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